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A home for all within planetary boundaries: Pathways for meeting England's housing needs without transgressing national climate and biodiversity goals

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ABSTRACT

Secure housing is core to the Sustainable Development Goals and a fundamental human right. However, potential conflicts between housing and sustainability objectives remain under-researched. We explore the impact of current English government housing policy, and alternative housing strategies, on national carbon and biodiversity goals. Using material flow and land use change/biodiversity models, we estimate from 2022 to 2050 under current policy housing alone would consume 104% of England's cumulative carbon budget (2.6/2.5Gt [50% chance of < 1.5 °C]); 12% from the construction and operation of newbuilds and 92% from the existing stock. Housing expansion also potentially conflicts with England's biodiversity targets. However, meeting greater housing need without rapid housing expansion is theoretically possible. We review solutions including improving affordability by reducing demand for homes as financial assets, macroprudential policy, expanding social housing, and reducing underutilisation of floor-space. Transitioning to housing strategies which slow housing expansion and accelerate low-carbon retrofits would achieve lower emissions, but we show that they face an unfavourable political economy and structural economic barriers.

1. Housing infrastructure and the Sustainable Development Goals

The Sustainable Development Goals (SDGs) outline humanity's aspirations for achieving high living standards for all without harming nature or modifying the climate system. However, unless the environmental impacts of economic expansion fall at a rate considerably faster than at any point in human history over the coming decades (Hickel and Kallis, 2019; Jackson and Victor, 2019), then there will be trade-offs between the environmental and economic objectives of the SDGs (Spaiser et al., 2017; Hickel, 2019). One such potential trade-off is that between built infrastructure expansion (underpinning multiple SDGs; Thacker et al., 2019) and climate (SDG 13; Müller et al., 2013) and biodiversity objectives (SDGs 14&15; zu Ermgassen et al., 2019). By 2060, an estimated >230 billion m^2 of additional built floor area will be added to the global building stock, equivalent to the built area of Japan each year (UNEP and IEA, 2017). The ecological impacts of this unprecedented infrastructure expansion will be profound (Müller et al., 2013; Laurance et al., 2015).

Navigating trade-offs between nature and infrastructure construction is a grand challenge – we need enough infrastructure to meet the transportation, communication, health, energy, production and housing needs of all, but excess infrastructure risks failing to address human needs whilst inflicting damage that threatens the integrity of the Earth system (O'Neill et al., 2018; Brand-Correa et al., 2020; Fanning et al., 2021). Haberl et al. (2019) show that for societies below a threshold of approximately 50 t of concrete per capita (concrete represents 45% of global material stocks by mass), there is coupling between increasing

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infrastructure and human wellbeing, measured by the social progress index (SPI) (see also Donaldson, 2018; Thacker et al., 2019). However, above this threshold, the relationship dissolves. The starkest example is that New Zealand achieves a higher SPI than the Czech Republic with approximately 20% of the per-capita material stocks (Haberl et al., 2019).

The thorniest problems contain the potential for direct trade-offs between societal priorities – such as between meeting fundamental human needs and remaining within the planet's 'safe operating space' (Fanning and O'Neill, 2019). Housing infrastructure represents such a challenge: housing is recognised as a fundamental human right, and in commonly-used needs-based conceptualisations of wellbeing formalised by Doyal and Gough (1984), Max-Neef (1991) and Rao and Min (2018). Housing expansion to address unmet basic human needs is clearly essential. Yet, processes linked to housing provision are, under current production technologies, powerful drivers of both biodiversity loss and climate change. Twenty-four percent of all threatened species on the IUCN Red List are threatened by commercial and residential infrastructure expansion (https://www.iucnredlist.org/), and yet more by construction mineral supply chains (Torres et al., 2021, 2022). Infrastructure's climate impacts come from the greenhouse gas emissions embedded in the production, operation and maintenance of infrastructure - emissions from housing and construction contribute approximately 27% of all annual global carbon dioxide emissions (UNEP, 2020).

However, infrastructure and housing construction remain core economic sectors in most advanced economies. Whilst often justified on the grounds of affordability, employment, or providing enabling conditions for increasing productivity (Thacker et al., 2019), the lack of an obvious macro-level wellbeing-infrastructure stock relationship in infrastructure-abundant economies suggests other factors might also help explain the economic salience of specific infrastructure classes. For example, Mattioli et al. (2020) explore the political economy of road infrastructure and car-dependence, and identify a range of socio-political dynamics that lock society into a high car use, high ecological consumption pathway. Political-economic factors might also play an important role in other infrastructure sectors, such as housing, and help partially explain infrastructure proliferation even in cases where the social benefits are unclear.

1.1. England's housing and sustainability policy context

This paper explores these issues in the context of England's housing affordability crisis: England represents a particularly salient case study, as it simultaneously has abundant housing stock, unmet housing need, and legally-binding environmental policy goals reflecting national contributions to addressing key planetary boundaries (Steffen et al., 2015). England has under-occupied housing stock (see Section 2; Mulheirn, 2019), but one recent estimate suggests up to 7.9 million people currently experience some symptoms of unmet housing needs (National Housing Federation, 2020); predominantly because England has one of the highest rates of housing unaffordability (Downie et al., 2018; National Housing Federation, 2020). Additionally, the country's population is still growing. The government's policy response is to build more housing, having committed to supplying 300,000 new homes per year by the mid-2020s (Wilson and Barton, 2021).

However, there is limited discussion of the ecological implications of this strategy in policy reports. On the climate side, the government has committed to net zero by 2050, and England's cumulative carbon budget from 2022 to 2050, compatible with a 50% chance of staying below 1.5 °C, is approximately 2.5GtCO_2e (5GtCO_2e is the remaining carbon budget for England implied by the government's Net Zero strategy; Jackson, 2021; Supporting information).

The dominant approach to housing sustainability in English policy reports is on reducing the ecological impacts of the existing and future housing stock whilst taking rapid housebuilding rates as given. The overwhelming focus in official government documentation regarding the housing affordability crisis is on building more homes (DCLG, 2017; MHCLG, 2021a; OECD, 2021). However, home energy and electricity use represents one-fifth of total emissions (CCC, 2019, p11). Extensive analyses have demonstrated how to achieve net zero operational emissions across the buildings and residential sector, including retrofitting the existing stock (CCC, 2019, 2020; RICS, 2020; EAC, 2021; NEF, 2021). Policy mechanisms have been proposed to accelerate uptake of energy-saving domestic innovations (e.g. 'green offsets'; 'green land value tax' (Muellbauer, 2018; Cheshire and Hilber, 2021)). Notably, shifts towards more equitable consumption of floor space/capita are not mentioned in government strategy, despite having been empirically identified as essential to achieving decarbonisation targets (Serrenho et al., 2019; Hertwich et al., 2020; Pauliuk et al., 2021).

However, there have been no reductions in annual emissions from buildings observed since 2015 (Committee on Climate Change, 2020, p110). Fifty-four percent of all homes in England have energy performance certificate (EPC) ratings of D or worse, and the Committee on Climate Change recommends all homes exceed this standard by 2028 (EHS, 2021). Nearly all require retrofitting to be consistent with the 2050 Net Zero target (EAC, 2021). For newbuilds, the percentage possessing an EPC band 'A' has varied between 1 and 1.5% each year from 2014 to 2020 (MHCLG, 2021b). Homes constructed today which are not compliant with 2050's net zero goal will have to be retrofitted at potentially prohibitively high future cost (Serrenho et al., 2019).

On the biodiversity side, the 2021 Environment Act commits the government to implementing a legally-binding target to halt wildlife declines nationally by 2030, and from late 2023 will mandate that all new developments achieve a 'Biodiversity Net Gain'. Biodiversity Net Gain aims to resolve trade-offs between new construction and impacts on nature. The policy will mandate that all new developments leave biodiversity better off than they found it, as measured using the Biodiversity Metric, a simple habitat-based biodiversity indicator (zu Ermgassen et al., 2021). However, recent empirical work has demonstrated that the policy's impacts on biodiversity remain ambiguous – planning applications achieving 'net gain' in a set of early-adopter councils were associated with a 34% reduction in the area of greenspace despite claiming a 20% improvement in biodiversity overall, and major governance gaps were identified, risking the successful delivery of these promised compensatory biodiversity improvements (zu Ermgassen et al., 2021). Given uncertainty about Biodiversity Net Gain's effectiveness, preventing unnecessary land use change consistent with the mitigation hierarchy remains essential (Phalan et al., 2018; Bull et al., 2022).

Whilst supply-side sustainability measures are essential, policy focusing solely on operational impacts might signal that housing proliferation can continue without trading-off against environmental policy objectives or compounding existing decarbonisation challenges in the sector. However, housing proliferation is associated with unavoidable material impacts, including embodied carbon emissions in construction, and urban land take affecting biodiversity. The construction of poor quality housing today also induces 'lock-in' effects, passing additional decarbonisation costs into the future (Serrenho et al., 2019).

1.2. Rationale

In this paper, we explore whether the English government's expansionary housing policies effectively address unmet housing need, and their compatibility with national biodiversity and decarbonisation goals. We review the political economy of England's current policy response, and outline alternative pathways to meeting England's housing needs without undermining national sustainability objectives. This study therefore implicitly explores solutions for simultaneously achieving infrastructure and housing-related SDGs (9, 11), and ecological SDGs (13, 15). To our knowledge we are the first to simultaneously estimate the biodiversity and carbon impacts of housing expansion in England, present the emissions of housing relative to England's cumulative carbon budget, and investigate the sustainability implications of alternative strategies for addressing the housing affordability crisis and supply-side/demand-side debates about housing affordability. Reducing the operational emissions of existing housing is already recognised as one of the largest challenges in the UK's decarbonisation strategy (CCC, 2019; Serrenho et al., 2019; RICS, 2020; EAC, 2021; NEF, 2021). However, emissions from new housebuilding are still a substantial contributor (Drewniok et al., 2022b), and they have received much less attention. We therefore begin to fill the gap in research around the potential impacts of reducing housebuilding and the political economic barriers and solutions.

The paper is organised as follows. Section 2 reviews the causes of the housing unaffordability crisis, reviewing evidence suggesting that simply expanding housing supply may not address key ultimate drivers of unmet housing need. Section 3 presents our novel analyses of the carbon and biodiversity impacts of alternative strategies for the English housing stock. Section 4 summarises the political economy of housing expansion in England, identifying 'growth-dependencies', unrelated to England's fundamental housing needs, that make its economy structurally dependent on housing expansion. Section 5 proposes policies for addressing unmet housing need whilst minimising conflicts with national sustainability policies. Section 6 concludes.

2. The causes of housing unaffordability

Understanding the true drivers of housing unaffordability is key to identifying solutions that can increase housing need satisfaction without substantially increasing the housing sector's emissions and ecological impacts (i.e. improving the ecological efficiency of the housing 'provisioning system'; Fanning et al., 2020). England's housing affordability crisis is characterised by rising average prices relative to incomes, falling rates of homeownership matched by rising levels of renting, homelessness, and general housing inequality spanning both housing space/capita and the socio-economic and demographic distribution of housing wealth (Tunstall, 2015; Arundel, 2017; Ryan-Collins et al., 2017; Gallent, 2019). Across England and Wales, the ratio of median house price to median gross annual earnings has risen from an average of just below 4:1 in 1998 to almost 8:1 by 2020, with London reaching 12:1 (ONS, 2021a). This has priced out younger and lower-income cohorts from the housing market in many of the cities where jobs are created. However, at the same time, the consumption of housing space has been rising, from 35.2m^2/capita in 1996 to 41.1m^2/capita in 2019 (Serrenho et al. 2019; EHS 2020a, Annex).

Whilst average housing rents have largely tracked incomes, the housing cost to income ratio, which incorporates all housing costs and compares these to post-tax incomes on annual basis, has risen from around 10% in the early 1980s to 35% now for private renters, with similar dynamics for housing associations (Resolution Foundation, 2017). This has been driven by the liberalisation and privatisation of the rental market and declines in housing benefit, coupled with stagnating wages for renters, most of whom occupy the bottom half of the income distribution (Coulter, 2017).

2.1. Supply-side explanations

In UK policy-circles, explanations of the affordability crisis are dominated by supply-side explanations. Multiple major reviews of the UK's housing market have concluded the reason for high prices is due to inadequate provision of new homes relative to rising demand (Lyons, 2014; DCLG, 2017; Wilson and Barton, 2021).Both major political parties have emphasized the supply-side, with in-power Conservatives placing more emphasis on reforming an inefficient planning system (MHCLG, 2021a), and Labour on building more social housing (Labour Party, 2019). Other solutions include penalising developers for holding undeveloped land with planning permission secured (representing approximately 1 million unbuilt homes in the UK; Local Government Association, 2021), and encouraging innovation within the sector (DCLG, 2017). A substantial body of academic research also emphasizes supply-side explanations (Brown and Glanz, 2018; Cheshire, 2018).

However, a body of empirical evidence casts doubt on solely supply-side explanations. On planning, approximately 90% of planning applications in the UK are approved (MHCLG, 2021c). Government household and housing stock data show that the UK has a surplus of dwellings relative to households (Fig. 1). This surplus has grown from 660,000–1.23 million homes from 1996 to 2019 (Mulheirn, 2019). This pattern is consistent across the country: for example, London has a higher proportion of surplus dwellings than the national average. In recent years the number of new households has been consistently outstripped by additions to the housing stock (ibid).

Even if there are housing supply constraints, evidence suggests that expansion of the housing stock may have a limited effect on housing affordability. Estimates of the sensitivity of UK house prices to increases in housing stock consistently show that a 1% increase in housing stock per household delivers a 1–2% reduction in house prices (Auterson, 2014; Oxford Economics, 2016; MHCLG, 2018). This is minimal in the context of a 181% increase in mean English house prices from 2000 to 2020 (£84,620–£253,561; HMLR, 2022).

Beyond the question of general housing shortages, it is more universally agreed that there are shortages in social housing which targets the needs of those struggling to afford market-rate homes or rents. Government-led construction of social housing was central to UK post-war social policy, with local authorities constructing the majority of housing in the 50s, peaking at 155,000 new homes in 1967, before declining in the 70s and 80s as the government ended the New Towns programme and various legal judgements increased the cost of state-led compulsory purchase of land for housebuilding (Ryan-Collins et al., 2017; Wilson, 2021). Social housing stocks were sharply reduced by the Thatcher government's 'right-to-buy' policy which facilitated the discounted transfer of approximately 2 million properties from the state to private owners, 40% of which are now estimated to be on the private rental market (Inside Housing, 2017; Christophers, 2020). Recent estimates suggest there is currently a need for an additional 1.6 million dwellings at social rent (National Housing Federation, 2020).

2.2. Demand-side explanations

Demand-side perspectives on house price unaffordability emphasise the interaction of multiple complex processes that cause ever-increasing capital to flow into the housing sector, competing for finite supply (Gallent et al., 2017, 2018; Ryan-Collins, 2018; Kazi and MacFarlane, 2022). A key observation is housing has multiple functions: it is both a consumption good and a means of accruing wealth. Evidence suggests the demand for both types of use has increased over time and would appear to provide more explanatory power in understanding rising house prices than supply.

Considering consumption demand first, UK housing and land has a high income-elasticity of demand - as incomes rise households spend more of their income on housing relative to other goods (Cheshire and Sheppard, 1998). One estimate across two UK cities found that a 10% increase in incomes leads people to spend about 20% more on space in houses and gardens, with homeowners having a higher income elasticity of demand than renters (ibid). As mentioned above, high-level data shows that as incomes have risen, households in England have on average been occupying more space over the last 25 years (35.2m^2/person-41.1m^2/person from 1996-2019; Serrenho et al. 2019). A recent long run model of UK house prices found consumption demand driven by rising incomes to be the most important single factor (Meen and Whitehead, 2020).

Other studies have pointed to the effects of low real interest rates in increasing the demand for housing as a financial asset (Miles and Monro, 2021; Mulheirn, 2019), whilst others have pointed to weakening credit constraints as the 'elephant in the room' in explaining rising house

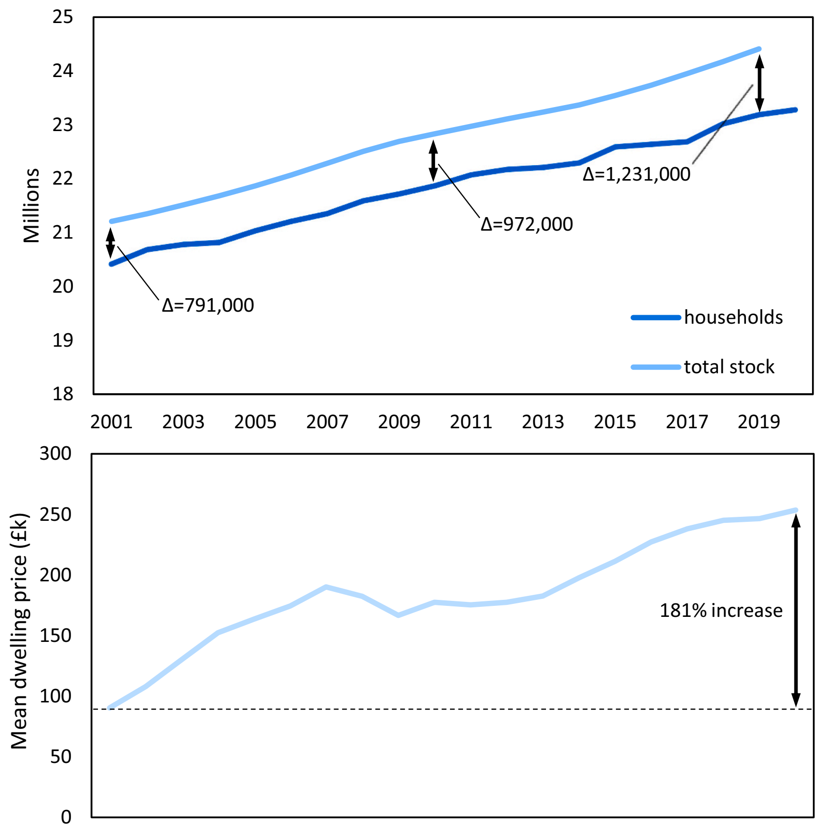

Fig. 1. Comparison of the total number of dwellings and households in England, and changes in mean dwelling prices, from 2001 to 2020. Top panel: Numbers of households (2001–2015 data from ONS, 2018, Fig. 10, "household estimates"; 2015–2020 data from ONS, 2021b, Table 5, England), dwellings (MHCLG, 2021d, Table 104), and surplus dwellings (households - dwellings) in England. Bottom panel: annual mean dwelling price in England (HMLR, 2022).

prices (Aron et al., 2012; Ryan-Collins, 2018; Bezemer et al., 2021). The liberalisation of mortgage finance in wealthy economies since the 1980s, coupled with financial innovations such as securitisation encouraging institutional investors to enter the housing market, have led to enormous increases in capital flowing in to the housing sector, competing for a finite supply of desirably located residential land, with inevitably inflationary consequences (Aalbers, 2017; Gallent et al., 2017, 2018; Ryan-Collins, 2018; Blakeley, 2021).

In the UK, financial deregulation and liberalisation supported an increase in UK-based banks' credit creation for mortgage lending from around 15% of GDP in 1980 to 60% by 2008 whilst lending to businesses increased from 10% to just 30% (figures remain similar in 2020; Bezemer et al., 2021). Whilst with most commodities, rising prices will lead to falling demand, rising house prices relative to income create more demand for mortgage credit, whilst real estate's attractiveness as a form of collateral (being difficult to hide and increasing in value) gives banks confidence to continue to meet this demand. This creates a positive feedback loop or "housing-finance cycle" (Ryan-Collins, 2021) which can be hard to break out of without repercussions for financial stability and the wider economy. These dynamics also exacerbate housing inequality as purchasers with existing housing collateral can secure additional mortgage loans at lower interest rates, out-competing first time buyers for new property that comes on to the market. In doing so, the effect is to push up prices of housing beyond that which it may have reached had only owner-occupiers been competing.

The attractiveness of land and housing as financial assets have fuelled a rise in foreign investment in the UK property sector. Between 2014 and 2016, 13% of all homes purchased in London were bought by overseas investors, and around half of these were of housing valued at <£0.5 m (Wallace et al., 2017). Between 2009 and 2015 complex corporate structures mostly registered in offshore tax havens purchased nearly 28,000 London properties and land parcels at an estimated value of £100 billion (Crerar and Prynn, 2015). A recent investigation found that the number of dwellings with owners registered abroad has tripled from 2010 to 2021, representing nearly 1% of England and Wales' entire dwelling stock (Clarence-Smith, 2021).

Government policies have contributed to these dynamics, with a general shift in policy away from subsidizing the creation of the housing stock towards subsidizing the demand for homeownership and private renting. Homeownership as an asset class receives favourable tax treatment, notably with the 1963 abolishment of imputed rent and capital gains tax exemptions for primary residences (Oxley and Haffner, 2010; Ryan-Collins et al., 2017). A range of mortgage subsidies have been introduced over the years, including the ability to offset taxation against interest payments on investment properties (abolished in the early 2000s) and a range of schemes supporting first time buyers. Recent evidence suggests these latter schemes had the perverse effect of increasing house prices as the increasing demand was capitalised into prices (Carozzi et al., 2019).

Additionally, government policy has created incentives for the purchase of second homes as investment properties. Most notably, the 1988 Housing Act made private renting more attractive for investors by strengthening landlords' grounds for repossession, abolishing fair rent appeals and reducing the minimum notice period of eviction from one year to six months (Leyshon and French, 2009). The latent demand for second homes was realised in 1996 with the introduction of 'buy-to-let' (BTL) mortgages, which led to a flood of new credit into the housing market. By 2008, BTL made up 11% of total mortgage advances (ibid).

Rising rents have also led to huge increases in housing benefit being paid out to lower-income renters, which amounts to a significant government subsidy for landlords (housing benefit was estimated to cost the government £23.4 billion, 3% of the national budget, in 2019) (Ryan-

Collins et al., 2017; Office for Budget Responsibility, 2018; Christophers, 2020). Since the vast majority of landlords come from the top 20% of the income distribution (Christophers, 2020), these dynamics further increase housing and earnings inequality.

In summary, this exploration of the drivers of housing unaffordability suggests the problem may be less with the total supply of housing units and more with their distribution across the population and 'over-consumption' by wealthier groups, enabled by rising incomes and easy credit conditions. Policy reforms that could dampen the demand for housing beyond a basic level of need could theoretically enable the UK housing system to satisfy greater housing need without relying on rapid housing expansion. This is welcome, as a solely supply-side explanation would imply that the only way to satisfy more housing need is through housing expansion, despite the inherent environmental impacts. Next, we explore the ecological impacts of expansionary housing policies, and compare them with alternative pathways for meeting housing needs.

3. The environmental impacts of housing proliferation

3.1. *Potential baseline biodiversity impacts of housing expansion without policy action*

How much housing expansion in England will conflict with the 2030 species abundance target is currently unknowable, as Biodiversity Net Gain will first be introduced in late 2023 and its effectiveness is unproven, and no models yet exist for predicting changes in species abundance in response to land use changes in England. Our simple approach here is to draw on existing models estimating changes in species richness (as a proxy) from land use change, and predicted housing expansion, to generate a high-level estimate of the biodiversity impacts of predicted housing expansion without policy action, which can roughly represent how effective Biodiversity Net Gain and species mitigation policies will need to be to halt biodiversity loss from housing expansion from now-2030. This land use change model does not include the land take associated with biodiversity offsets purchased off-site to achieve developments' biodiversity net gain commitments (i.e. it implicitly assumes that all biodiversity units will be delivered on-site). This is justifiable on the grounds of zu Ermgassen et al. (2021) who identified in their sample of developments achieving net gain that the vast majority (93%) of biodiversity units were delivered on-site; although we recognise the government's own market analysis suggests up to 50% of units may be delivered off-site (eftec, 2021). In Section 5 we then draw on results from recent evaluations of Biodiversity Net Gain and species mitigation measures to discuss improvements required to deliver this aim (Hunter et al., 2021; zu Ermgassen et al., 2021).

We use the spatial projections for urban expansion in England from 2006 to 2031 from Eigenbrod et al. (2011), and input these into the biodiversity module of the Natural Environment Valuation modelling suite (Binner et al., 2019). The biodiversity module represents an ensemble of species distribution models which give the probability of species presence in each 2 km grid cell across England for 100 species of conservation priority, given the land use in that cell (Wright et al., 2019). For each cell, the probability of species occurrence under the chosen land use is then summed for all species, and this can be compared with the baseline land use to estimate the effect of housing development on richness of species important to conservation (Supporting

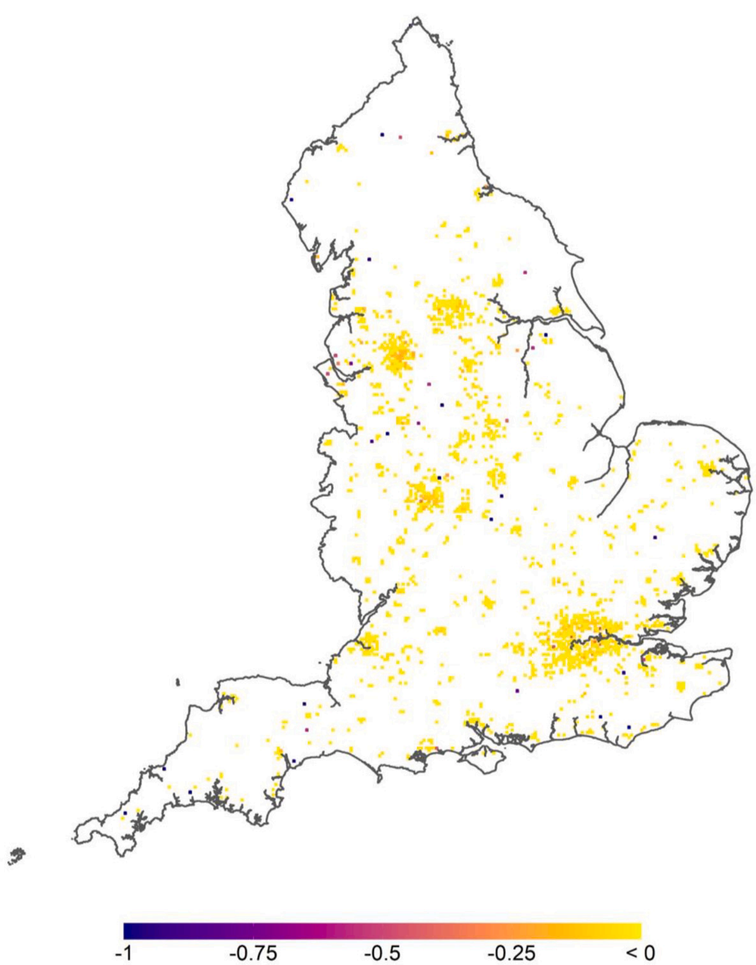

Fig. 2. Estimated impact of urbanisation on biodiversity, measured as species richness per hectare for 100 species of conservation priority in England.

information).

The model estimates that 12,519 ha of farmland will be lost per year from 2006 to 2030 to urban development in the UK under the assumption of constant housing densities over time (Eigenbrod et al., 2011; Fig. 2), which is roughly the same as the mean conversion of agriculture and undeveloped land to developed land in England from 2013 to 2018 (13,956 ha; Ministry of Housing, Communities, and Local Government, 2020a, Table P350). This equates to an average loss of biodiversity of approximately 0.04 species per hectare or an average 5.7% loss in species richness in the areas being developed (Fig. 2). For housing expansion not to conflict with England's 2030 wildlife abundance targets, Biodiversity Net Gain and species mitigation policies will have to fully compensate for these losses, or the rate of land take for housing could be reduced to avoid these impacts on biodiversity initially.

3.2. Potential carbon impacts of housing expansion

To estimate emissions, we use two recently-developed models and reparameterise them to reflect current data and alternative scenarios for housing in England: a high-resolution material flow analysis estimating the embodied carbon in housing construction developed by Drewniok et al. (2022b, 2022a), and the operational housing emissions model developed in Serrenho et al. (2019).

Drewniok et al. (2022a) estimate the amount and type of materials used in the production of new dwellings by combining information about the proportion of different dwelling types from the English Housing Survey (EHS, 2020b) with case study archetypes for each dwelling type identified from letting agency or developers' websites. For each case study, information about the layout is used to estimate the dimensions for substructure, structure, roof, partitions, cladding, wall and ceiling finishes, windows and doors. The analysis excludes insulation and fixtures and fittings. For each building element, the most common technologies are estimated based on information from the English Housing Survey (EHS, 2020b) and NHBC standards (nhbc-standards.co.uk), and the material intensities for the different technologies are modelled based on NHBC standards. For elements that use a mix of technologies throughout the building stock, the share of alternative technologies is estimated through discussions with industry partners. The material quantities for each dwelling typology are then normalised by gross internal floor area. Similar methods are used to determine the material quantities for the conversion of non-domestic to domestic buildings (which makes up approximately 8% of net additions to the housing stock), except it is assumed that the foundations and upper floors are reused (i.e. unassociated with embodied emissions), and it is assumed that 50% of the remaining building structure is reused. The total volume of materials required includes a small wastage rate, consistent with current building practice.

To estimate the emissions embodied in all of these materials, Drewniok et al. (2022a) use life cycle assessment methods consistent with British standards (BSI, 2011). Their analyses include the emissions associated with the materials and construction process up to practical completion, which represents approximately 70% of the whole life embodied emissions for residential buildings (Gibbons and Orr, 2020). Carbon coefficients for each material are taken from the Inventory of Carbon and Energy (ICE, 2019), and for materials not listed in the inventory, values are taken from their Environmental Product Declarations. Transport emissions are estimated based on the average emissions of road freight. The model produces estimates of embodied emissions of housing which are consistent with other results reported in the literature, including those calculated by alternative methodologies (e.g. Steele et al., 2015).

To estimate the operational emissions of the housing stock we use the operational emissions model developed in Serrenho et al. (2019). They estimate the operational emissions of the existing stock by, firstly, identifying the Environmental Impact Rating (EIR) and floor area for all England's dwellings (with the year 2018 as a baseline) using information from the English Housing Survey (EHS, 2020c). They then use the government's standard method for translating dwellings' EIR into annual emissions using the equation (DECC, 2014):

$$O = \begin{cases} (A+45)*10\left(\frac{40}{19}-\frac{EIR}{95}\right), if\ \frac{O}{A+45} \geq 28.3 \\ (A+45)*\left(\frac{100-EIR}{1.34}\right), if\ \frac{O}{A+45} < 28.3 \end{cases}$$

where O represents the annual emissions in kg CO_2 and A represents each dwelling's floor area in m^2.

Both models then enable testing the emissions associated with various scenarios for the future of the housing stock. The Drewniok et al. (2022b) model estimates future embodied emissions associated with different housebuilding rates. The types of housing being added to the stock each year is assumed to reflect the distribution across different housing types under the baseline year. The model includes industry's own projections for the decarbonisation of production of different building materials from technological innovation (e.g. assumes 36% decarbonisation of concrete production by 2050 in line with the industry's net zero roadmap; GCCA, 2021), but discounts the use of negative emissions technology as it is unproven as scale. The model allows the user to vary multiple inputs, such as the degree of material decarbonisation over time experienced by various building materials or the demolition rate, but for the sake of simplicity interpreting the results of the differences between our housing scenarios, we maintain nearly all inputs constant across all of our scenarios.

The Serrenho et al. (2019) model takes the baseline operational emissions of the existing stock and of newbuilds in 2018, and then simulates a linear rate of decarbonisation of both types of housing under varying assumptions about the time to decarbonisation, and the total degree of decarbonisation, for both housing classes (Supporting information). This decarbonisation trajectory reflects both the increasing efficiency of the housing stock through retrofitting and the decarbonisation of the electricity grid. We update the original Serrenho et al. (2019) model by adopting the 2021 demolition rate as used in Drewniok et al. (2022b).

We simulate three scenarios for the future of the housing stock (Table 1) that correspond to alternative strategies for meeting England's housing needs from 2022 to 2050 (Fig. 3). Scenario 1 represents the government's current housing strategy. Scenario 2 represents a highly ambitious supply-side greening strategy where the rate of housebuilding remains aligned with government expansion targets, but new home standards are introduced so all newbuilds are zero carbon from 2035 and the existing stock is retrofitted so that it is as efficient as contemporary newbuilds (i.e. newbuilds constructed in 2018 as in Serrenho et al., 2019) by 2035. Scenario 3 implements the same ambitious roadmap for decarbonising newbuilds but coupled with extremely ambitious decarbonisation of the existing stock (so the existing stock achieves zero emissions by 2050) and more efficient use of housing space to reduce the need for new housing construction and the associated embodied emissions (to zero net additions by 2035). All scenarios are policy-relevant (i.e. derived from the government's Net Zero strategy or other policy reports; Table 1).

Under Scenario 1, the housing stock consumes 104% of England's cumulative carbon budget consistent with a 50% probability of remaining within 1.5 °C of heating by 2050, or 52% of the cumulative carbon budget of the government's balanced net zero pathway (Fig. 3). Ninety-two percent of emissions come from the existing stock, and 9% is embodied in the construction of new housing. The operational and embodied emissions of new housing consume 12% of the cumulative carbon budget for 1.5 °C. Scenario 2 consumes 70% and 35%, and Scenario 3 60% and 30%, of the 1.5 °C and government carbon budgets respectively.

By far the most impactful policy for reducing housing's conflict with

Table 1
Simulated scenarios for the future of the housing stock from 2022 to 2050. We hold a range of assumptions constant across all three scenarios to improve comparability, such as material decarbonisation rates, housing typology, rate of conversion of non-domestic to domestic buildings (Supporting information). The policy justifications for the assumptions we vary are: 1) Government's existing housebuilding target (Wilson and Barton, 2021). 2) Consistent with Net Zero strategy goal "ensure that all homes meet a net zero minimum energy performance standard before 2050, where cost effective, practical, and affordable." (BEIS, 2021a). 3) Consistent with Net Zero strategy goal "We will introduce regulations from 2025 through the Future Homes Standard to ensure all new homes in England are ready for net zero by having a high standard of energy efficiency and low carbon heating installed as standard." Note that net zero ready does not mean zero carbon, but able to to achieve zero carbon in the future when the electricity grid is decarbonised, hence the 2035 target date. 4) Linear extrapolation of the decarbonisation rate of the emissions from homes from 1990 to 2019. This extrapolation considerably exceeds recent decarbonisation trends, as there has was no decarbonisation in domestic emissions from 2014 to 2019 (BEIS, 2021b, Table 1.2; Supporting information). 5) Consistent with Net Zero strategy goal of "Consulting on phasing in higher minimum performance standards to ensure all homes meet EPC Band C by 2035, where cost-effective, practical and affordable." (BEIS, 2021a).

Key assumptions	Business as usual	Supply-side greening	Strong sustainability
Housing construction rates	300,000 net additions per year to 2050[1]	300,000 net additions per year to 2050	Linear decrease from today's level to zero net additions by 2035
Unoccupied housing	Current level	Current level	No vacant homes; fully occupied
Time to decarbonisation of new housing	2050[2]	2035[3]	2035
Retrofit rate	Halve operational emissions of the existing housing stock by 2050[4]	Retrofit all to 2018 standards by 2035[5]	Retrofit all to zero carbon by 2050[2]

climate targets (but not biodiversity) is rapid retrofitting of the existing stock (coupled with decarbonising the electricity grid) – retrofitting all homes to emissions standards of today's newbuilds by 2035 could avoid 0.8GtCO_2e, equivalent to 32% of the cumulative carbon budget for 1.5 °C. Going even further and decarbonising the existing stock entirely by 2050 could save 38% of the budget for 1.5 °C.

However, slowing the rate of housebuilding and improving the standards of new construction can also play a key role, especially when we consider later government carbon budgets (the government agrees national carbon budgets for 5-year periods; e.g. the UK's 'sixth' carbon budget from 2033 to 2037 has been set at 965MtCO_2e, approximately 827MtCO_2e for England alone) (Fig. 4). Reducing the rate of housebuilding to zero net additions by 2035 can save 6% of the cumulative budget for 1.5 °C by 2050 in avoided embodied and operational emissions. As we enter later carbon budgets, concrete and construction materials consume larger proportions of the budgets– even assuming decarbonisation rates aligned with industry net zero strategies (excluding their commitments to carbon capture and storage which are currently unproven; GCCA, 2021), embodied emissions in new housing construction under the government's targeted expansion rates consume 8% and 27% of the budgets for 2038–2042 and for 2043–2050 respectively (Fig. 4).

Alongside highlighting the recognised need for deep and rapid retrofitting of the existing stock, our analysis also reveals trade-offs between projected housebuilding as a mechanism for satisfying housing need and achieving national biodiversity and climate goals, empirically supporting multiple studies showing that reducing per capita demand for floor area from those with space in excess of their needs is essential to achieving sustainability goals (Serrenho et al., 2019; Pauliuk et al., 2021). So why do our policies for addressing housing need rely so heavily on housing expansion?

4. The political economy of housing expansion

The government's current strategy for satisfying housing need is an expansionary, high environmental resource consumption pathway, which if implemented in line with the assumptions of our Scenario 1 consumes the entire carbon budget for 1.5 °C on its own. Escaping this pathway will require overcoming daunting political economy constraints. Recent theoretical work in ecological economics has uncovered major structural barriers to reducing growth rates in various sectors of the economy (Stratford, 2020; Corlet Walker et al., 2021) – so called 'growth-dependencies' ("certain core aspects of human wellbeing become compromised when growth is either hard to come by or undesirable"; Corlet Walker and Jackson, 2021). In this section, we explore the expansionary lock-in created by several growth-dependencies in the housing sector.

The first is created by a combination of 1) the dependence of English homeowners on property as a source of financial security (especially in the context of ongoing welfare state retrenchment; Corlet Walker et al., 2021), and 2) the political influence of those homeowners. As discussed in Section 2, a key motivation for first-time buyers in the UK is to secure housing as an investment, in the expectation that past rates of house price appreciation will continue (Gallent et al., 2017). Recent homebuyers – who may have been enabled to purchase homes because of easy credit conditions – are particularly vulnerable to the state of the housing market, finding themselves "at the top of a pyramid scheme" (Gallent et al., 2018) reliant on continued asset-price appreciation and ongoing low-interest rates to not suffer significant financial harms. A fall in house prices induced by policies seeking to reduce the demand for housing as a financial asset would place these 'ordinary' homeowners (i.e. not institutional property investors) in an increasingly financially precarious position, potentially jeopardising their long-term financial security and even their ability to sell their house on without falling into debt. At scale, this could have a significant destabilising impact on England's entire economy.

The majority of the UK population fall into the homeowner category (63%), incentivised by half a century of government policy encouraging 'asset-based welfare' (building people's financial assets through their working life in order to compensate for relative reductions in state welfare provision, especially in old age; Doling and Ronald, 2010). As a group they are significantly more likely than non-homeowners to vote in elections, vote for the Conservative party, and participate in local planning processes (Coelho et al., 2017; Christophers, 2020). This political dominance has led to a competition between political parties as to who can best appeal to their preferences (Kohl, 2020).

The risk of financial and social harms associated with declining house prices, combined with the political influence of homeowners, therefore translates into a lack of political will to tackle demand-side-driven house-price appreciation. Increasing supply via more housebuilding, in contrast, is much more politically feasible option (despite its inadequacy for fully addressing unmet housing need). It is also in the interests of the politically-influential UK property lobby, which made £60.8 m in donations to the in-power Conservative party from 2010 to 2020, accounting for around 20% of the party's donations (Transparency International, 2021). Of these, 10% came from just 10 specific property-connected sources (ibid). In addition, one-quarter of conservative Members of Parliament are landlords (openDemocracy, 2021), presenting a potential conflict of interest against tackling house price inflation and policies supporting landlordism.

Secondly, the macroeconomic consequences of stagnating housebuilding would be profound. Sectors directly related to housebuilding (construction, housing and real estate) employ approximately one-eighth of the UK working population (ONS, 2021c). Moreover, the construction sector has historically experienced considerable levels of labour productivity growth (output per job rose by 13.7% from 1990 to 2019 (ONS, 2021d)), which theoretically means that construction must rise over time to maintain the same employment – the so-called

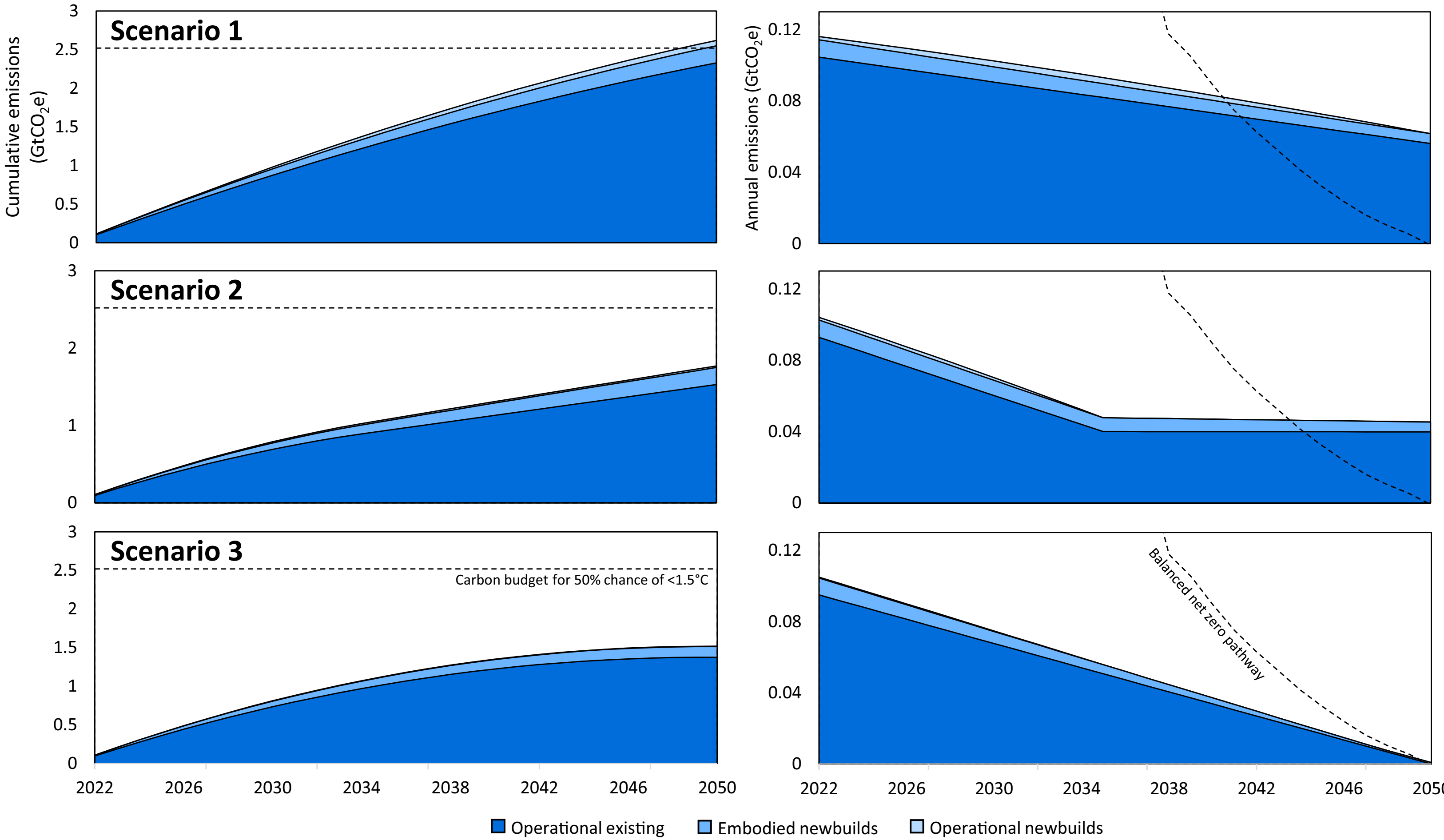

Fig. 3. The impact of alternative housing policy scenarios on the emissions of the new and existing housing stock. Left hand side: cumulative emissions from housing. Dashed line represents England's cumulative carbon budget by 2050 compatible with a 50% probability of remaining within 1.5 °C warming. Right hand side: annual emissions from housing. Dashed line represents England's balanced Net Zero pathway in the government's Net Zero strategy, which is consistent with <2 °C warming.

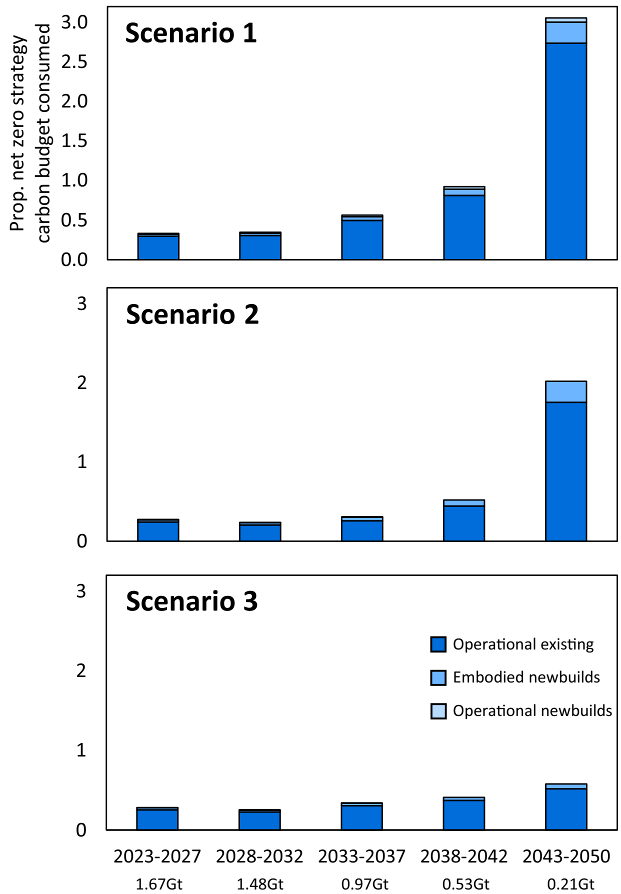

Fig. 4. The proportion of each of England's future carbon budgets consumed by housing under alternative policy scenarios. The fourth, fifth and sixth carbon budgets (2023–2037) reflect those embedded in UK legislation, seventh and eighth (2038–2050) reflect the sum of the annual emissions targeted under the government's Balanced Net Zero pathway, adjusted for the population of England compared with the whole UK.

'productivity trap' (Jackson and Victor, 2011). On the other hand, rising labour productivity may also reduce the costs of construction. The combined result of high employment in the sector and the labour productivity trap mean that even slowing the rate of growth in housebuilding (let alone halting it) could necessitate large structural changes in UK employment patterns.

Other macroeconomically important sectors are less directly dependent on housebuilding itself but would still face problems should demand-side repression policies be introduced. The financial sector is the best example, having become increasingly tied to property (see Section 2). With close to half of UK bank assets tied in to either domestic or commercial property, policies leading to a fall in house prices could materially affect the value of banks' collateral and their appetite for lending, with negative macroeconomic impacts in particular on smaller firms more dependent on bank loans (Ryan-Collins, 2018).

Third, decades of government policy to reduce funding for local government have changed how affordable and social housing is financed. Under the contemporary system, local government's ability to deliver affordable and social housing to meet locals' fundamental housing needs is explicitly tied to their acceptance of new private-sector housing construction. This has come about through the rise of 'section 106 agreements' in which developers pay local councils (or promise contributions to local public services) in return for receiving planning permission for their proposed developments. Such payments financed 37–63% of all affordable housing from 2008 to 2014 (Brownill et al., 2015). Councils therefore have limited power to satisfy housing need without accepting expansion of market housing.

Even decarbonising the existing stock (the most important determinant of the overall emissions of the housing sector in our models) faces a challenging political economy. Whilst aggressively upgrading the existing stock to achieving zero emissions from the existing stock by 2050 could save 38% of the carbon budget relative to business as usual (the difference in operational emissions of the existing stock between Scenarios 1 and 3), the housing sector is influenced by many vested interests who have financial stake in these high-consumption pathways. For example, research has revealed informal networks and coalition of actors from the natural gas, domestic boiler and connected industries promoting the discourse of a transition to 'green-gas' instead of the electrification of domestic heating that is favoured by the government's climate-related scientific advisory body (Lowes et al., 2020).

Combined, these growth-dependencies and political barriers not only underpin perpetual expansion of the housing stock, but also hinder the creation of a housing system that satisfies more housing need (Gallent et al., 2018). The asset poor are penalised by the ongoing inflation of house prices, but they have little political voice, disproportionately voting for out-of-power political parties (Milburn, 2019; Christophers, 2020). Reductions in state support for social housing has left a growing proportion of the population with no options other than be forced into the private rental sector (Ryan-Collins et al., 2017), which enables landlords to extract further rents (Stratford, 2020). This then absorbs an increasing proportion of the wages of the asset-poor, reducing their opportunities to save for a deposit (Ryan-Collins et al., 2017; Mulheirn, 2019), and contributing to why aspiring first-time-buyers are increasingly unable to enter the housing market.

The political economy of housing represents such a barrier to the implementation of systemic solutions to housing unaffordability that it has led housing scholars to argue that we are trapped between "the unimaginable and the unthinkable": either an unimaginable (and unsustainable) level of housebuilding, or an unthinkable definancialisation of the housing sector (Gallent et al., 2018), which runs counter to the interests of the homeowner classes and other powerful vested interests such as the construction and financial sectors.

Our analysis demonstrates that continued housing expansion with limited retrofitting of the existing stock as a mechanism for meeting housing need conflicts with England's ecological targets, and our political-economic review shows why we are locked into pathways of housing expansion regardless. Next, we explore policies for satisfying greater housing need whilst minimising ecological costs. We review three main areas: policies for satisfying greater housing need with the existing stock, definancialising housing, and improving the efficiency of the housing stock.

5. Policies for satisfying unmet housing need without undermining environmental policy targets

5.1. More efficient use of existing housing stock

The socio-economic distribution of the UK's existing housing stock and the consumption of housing services and living space is highly unequal. Tunstall (2015) shows a sustained reduction in housing space inequality from 1920 to 1980, counterbalanced by a significant increase from 1980 onwards and culminating in 2011 demonstrating the highest housing space inequality in over 50 years. By 2011 the most spaciously-housed decile of the population had five times the rooms/capita than the bottom decile (Dorling, 2015). Therefore, one key lever for meeting greater housing need whilst minimising housing expansion could be through policies incentivising greater equity in housing space consumption and more efficient use of the existing stock (Lund, 2019). We model complete utilisation of the housing stock (i.e. no vacant dwellings) as part of our Scenario 3.

There are multiple policy mechanisms for increasing the needs-satisfaction provided by the existing housing stock. There may be up to 1.2 million more homes than households in England (Mulheirn, 2019); these are a mix of second homes, foreign-owned investment homes, and other classes of empty homes. In 2018–2019, there were at least 495,000 s homes in England not rented out in the private rental market (MHCLG, 2020b). Rather than being treated as a public bad, second home ownership is incentivised under many current tax rules (e.g. second homes are eligible for council tax exemptions). In other jurisdictions with high house prices (e.g. Singapore, Vancouver), second homeowning is actively discouraged in order to free up stock to meet housing needs (Cheshire and Hilber, 2021). Various tax reforms could be used to disincentivise the consumption of housing space for second homes: e.g. Cheshire and Hilber (2021) propose the replacement of various existing, regressive property taxes such as council tax with an Annual Proportional Property Tax, including a 25% surcharge on second homes.

Foreign homeownership similarly contributes to housing underutilisation: between 2014 and 2016 42% of newbuilds purchased by foreign investors in London were left unoccupied (Wallace et al., 2017). Numerous jurisdictions (e.g. Canada, New Zealand) have brought in policies to reduce housing demand from foreign investors (Minton, 2021). Favilukis and Van Nieuwerburgh (2017) model the effect of taxes on out-of-town buyers on economic welfare and distributional impacts in New York, and find that transaction taxes on out-of-town purchases significantly benefit poorer residents and renters, depending on how the tax revenues are reinvested, although similar strategies in highly seasonal tourism-dependent economies could have negative economic effects (Hilber and Schöni, 2020).

There are also many other forms of empty homes in England (e.g. neglected properties, properties with deceased owners), with estimates derived from council tax data (known to be underestimates) suggesting approximately 650,000 empty homes in England in 2019 (House of Commons Library, 2020). Whilst local authorities do have some powers to bring empty homes back into use, additional policies have been suggested for increasing their capacity, including enhancing funding and legal powers to take control of empty homes and repurpose them for social housing (House of Commons Library, 2020).

Under-occupation of existing stock could also be addressed, although equity considerations are essential, as policies such as the 'bedroom tax' (which reduced the housing benefits of people in social housing who were deemed to have one or more 'spare' bedrooms) targeting the poorest families have had demonstrable negative consequences (Shelter, 2013). Consumption of inefficiently high levels of living space is implicitly subsidised through multiple mechanisms, such as a 25% council tax discount on single-occupied homes (Lund, 2019). Additionally, there are barriers to families downsizing even when desired, such as stamp duty costs (a one-off tax incurred upon buying a new home) (Strutt and Parker, 2015). Reducing transactions taxes might improve the efficiency of the use of the housing stock by improving occupier mobility (Hilber and Lyytikäinen, 2017; Best and Kleven, 2018). Some local authorities offer assistance and cash incentives to occupiers looking to downsize, to incentivise vacating underutilised stock (Lund, 2019).

However, changes to taxation regimes and other approaches to incentivise more efficient use of the housing stock cannot ultimately guarantee that housing space is not overconsumed in a market with potentially insatiable demand. Baden-Baden in Germany, for example, taxes second homes up to 35% of imputed (or contract) rent - on top of a (low) property tax - yet the number of second homes has been increasing. A more ambitious approach might be the implementation of resource caps on living space, with all households occupying in excess of a given floorspace threshold (reflecting what is required to meet an individual's housing needs) participating in a 'cap-and trade' system for floorspace, capping the total amount of floorspace nationally at some level empirically estimated to be feasibly decarbonised in line with national decarbonisation targets (Horn and Ryan-Collins, 2021).

All the policy proposals covered here are top-down approaches which face political barriers. Acknowledging that top-down policies are commonly implemented only if there is bottom-up support, another key dimension to increasing the efficiency of the use of housing space is cultural. From a sustainability perspective, the high income elasticity of demand for housing space presents a challenge as it implies that there will be a tendency for people to consume housing space (and therefore housing-related carbon emissions) in excess of their fundamental needs as incomes rise. However, this ultimately reflects cultural factors. There is limited empirical evidence for increases in housing space consumption improving subjective wellbeing for people who already have sufficient housing space to satisfy their needs, with evidence that people moving into larger homes quickly habituate and experience no or little long-run improvements in subjective wellbeing (Foye, 2017). Enjoyment of housing space is also affected by the quality of services provided in the surrounding neighbourhood (Sirgy, 2021). These suggest that voluntary reductions in the consumption of housing space by those with high levels of space could come with little adverse impact on wellbeing if embedded within high quality neighbourhood services. Culturally-transformative solutions to housing provisioning have been proposed, such as incentivising behavioural changes like increased co-living and space sharing to increase the needs-satisfaction per floor area of the existing stock (Corfe, 2019).

5.2. Reducing demand for housing as a financial asset

Structural reforms are also possible which reduce housing's appeal as a financial asset whilst increasing its affordability to lower-income groups – thereby theoretically satisfying greater need without changes to the total stock. Multiple solutions to speculatively-driven house price inflation have been proposed (Wijburg, 2020; Ryan-Collins, 2021), which broadly target land rents or the unearned incremental increase in house values that is not due to the owners' own productive investment (i.e. home improvements), and reforms that slow the movement of wealth into housing assets more generally.

The tax reforms mentioned in Section 5.1 in the context of increasing the efficiency of space use would also help reduce land rent extraction. The most comprehensive proposal for capturing land rents – with widespread support amongst economists - is a land-value tax, taxing the annual incremental increase in the unimproved market value of land. This tax has the benefit of capturing the increase in the price of land attributable to positive externalities of the state's and others' investments in the local area which improve public amenities and increase land value, thereby socialising the benefits that would otherwise be captured as rent (Ryan-Collins, 2021). An additional positive social impact of land value taxes would be to reduce landowners' incentives to strategically hold land unproductively. Such a tax would also discourage borrowing against property for speculative gain and dampen the aforementioned housing-finance cycle.

Given the model of asset-based welfare outlined in Section 4, to be politically acceptable these types of policy would need to be accompanied with public investments in the welfare state – especially pensions and social care – so that individuals are less dependent on house price for their long-term financial security.

Financial reforms could also assist in reducing house prices. The most powerful public bodies in relation to the quantity and price of mortgage lending in the economy are central banks and financial supervisors. Credit policies have been implemented by central banks historically in many high-income economies to reduce undesirable credit flows and encourage more productive and strategic lending (Bezemer et al., 2021). Historically, these favoured sectors like high value-added manufacturing and export industries and repressed lending for domestic consumption or house purchase. These became unfashionable in the 1980s with financial liberalisation but since the 2008 crisis, 'macroprudential' policies, aimed at repressing credit in particular undesirable sectors have returned (ibid). Housing-related macroprudential policy has included tighter loan-to-value and loan-to-income ratios for households on the demand side, whilst on the supply side requiring banks to hold more capital against certain types of real estate lending. The policy has proven to be effective in some cases in reducing mortgage credit flow (Muñoz, 2020). Such policies have been implemented by central banks and financial supervisors due to financial stability rather than affordability/sustainability concerns, but their use could be expanded. This would probably require greater coordination between central banks and governments, which has historical precedent (Ryan-Collins and Van Lerven, 2018).

In addition, currently most central banks do not include house prices (as opposed to the cost of housing) in their definition of consumer price inflation. This has allowed rapid increases in house prices to co-exist with very low or zero interest rates. Central banks could follow New Zealand's example and consider rethinking their measure of inflation to include housing costs which would create a stronger link between house prices and interest rates (Bloomberg, 2021).

In England, structural reforms to help redirect lending away from property and towards productive investment may be required. The UK banking sector is dominated by large shareholder banks who have a preference for larger mortgage loans and are heavily reliant on real estate as collateral. Reforms could promote the development of local/regional community-based banks (the primary holders of bank deposits in Germany) who develop strong relationships with firms as way of de-risking their loans (Ryan-Collins, 2021; Kazi and MacFarlane, 2022). This would also help develop a more resilient financial sector more generally that could help mitigate the macroeconomic growth-dependencies mentioned in Section 4.

Gallent et al. (2017) propose an innovative solution for reducing house prices for those seeking residence whilst maintaining opportunities for speculative investment. They discuss reforming planning law to distinguish between 'resident' and 'investment' housing, with different tax and ownership rules depending on each housing class. Households would be permitted to purchase a single resident home, which would be subject to high capital gains taxation when sold on to prevent homeowners from extracting economic rents. This 'resident' housing would be broadly designed to satisfy basic housing needs, leaving 'investment' housing as a financial asset to be consumed by investors, but without the flow of investment capital competing with ordinary homeowners for housing space and crowding out buyers looking to secure a home to meet their housing needs.

An additional set of key definancialisation solutions revolve around land ownership reforms. A simple way to ensure that the benefits of rising land values are not captured by rentiers is for land to be publicly-owned. Whilst 1.6 million hectares of publicly-owned land in the UK (8% of Britain's land area) have been privatised since the 1980s (Christophers, 2020), the state still owns large tracts of land; and there is international precedent to the state playing a larger role in socialising the benefits of land value uplift. For example, in Singapore, 90% of land is owned by the state and 82% of the population lives in public housing (Ryan-Collins, 2021). The state leases out land to developers for construction, and captures the land value uplift via increased lease prices on renewal.

5.3. Principles for newbuilds

Even implementing the above measures, there may still be unmet housing need from low-income households, and so new principles are required for newbuilds to be compatible with national sustainability targets whilst targeting unmet social needs. Directly targeting unmet needs requires primarily delivering social housing over ordinary market housing. Recent evidence from Finland demonstrates that the addition of social housing to the housing stock is initially much more likely to generate homes occupied by low-income households than market housing (for every 100 inner-city social homes added to the stock, 43 vacancies throughout the moving chain were immediately created for households in the bottom 50% of the income distribution, compared with 29 for market-rate homes, though the differences dissipate over time; Bratu et al., 2021). However, renewed construction of social housing would require a shift in government policy away from subsidizing private landlords to house low-income tenants (via housing benefit) and towards direct social housing construction.

From a climate perspective, in order for new additions to the housing stock today to not require retrofitting by 2050, the government would need to implement standards to ensure that all new homes achieve net zero operational emissions and minimise embodied emissions as soon as possible. Current government policy is for all new homes from 2025 to be 'zero carbon ready' (i.e. energy-efficient and supplied by electrical heating so that they decarbonise over time as the grid decarbonises), although notably this same goal had previously been set in 2006 for 2016, only to be scrapped in 2015 (H.M. Treasury, 2015; Oldfield, 2015).

In order for new housing to unambiguously contribute to achieving the end of wildlife declines by 2030, the implementation of both Biodiversity Net Gain and species mitigation legislation should be strengthened. Biodiversity Net Gain could be improved primarily by mandating that impacts to irreplaceable habitats and protected and unprotected wildlife sites (e.g. ancient woodlands) be avoided, and by putting governance and monitoring mechanisms in place to ensure that biodiversity promises made in planning applications materialise in reality (i.e. ensuring that regulators have sufficient tools to enforce the delivery of Biodiversity Net Gain; zu Ermgassen et al., 2021, 2022). In addition, the evidence base behind the effectiveness of species mitigation measures for housing development impacts remains weak, with only 29% of species mitigation measures demonstrably successful at preventing harms to wildlife of new housing (Hunter et al., 2021). Using only evidence-based mitigation techniques would increase confidence that housing expansion does not trade-off against wildlife abundance goals. Densification can also play an important role in reducing both carbon emissions and biodiversity impacts by reducing urban land-take and reducing car-dependency (OECD, 2020, 2021).

5.4. Retrofitting the existing stock

The key strategies for decarbonising the existing stock revolve around electrifying heating and improving home insulation and energy efficiency (reviewed extensively in CCC, 2019, 2020; RICS, 2020; EAC, 2021). Our models demonstrate that immediate action is required to dramatically reduce the emissions of the existing stock, as gradual decarbonisation pathways overlook that a large proportion of England's cumulative carbon budget to 2050 will be consumed in the next few years because of their high current operational emissions. For example, our models estimate the existing stock is currently consuming approximately 4% of the cumulative carbon budget (for 1.5 °C) each year.

6. Conclusion

Our study models the effects of the English government's housing policy and estimates that it risks consuming the entire national cumulative carbon budget consistent with 1.5 °C warming. It also demonstrates the urgency of retrofitting the existing stock, as retrofitting all existing homes and decarbonising the grid so homes are zero carbon by 2050 could save 38% of the cumulative carbon budget for 1.5 °C relative to a business-as-usual scenario which extrapolates current decarbonisation trends whilst achieving the government's construction targets. Meeting society's housing needs without relying on emissions-intensive housing expansion or speculative technological innovations relies on satisfying greater housing need through the existing housing stock. Accelerating retrofits, increasing the environmental standards of newbuilds so they achieve zero carbon and no net impact on wildlife populations (by strengthening Biodiversity Net Gain policy and species protections), and reductions in housing expansion rates, all play a role if the housing sector is to contribute to national sustainability objectives.

However, the policy innovations that could encourage greater housing need satisfaction from the existing housing stock (e.g. tax reforms, macroprudential policy) face an intimidating political economy. Nevertheless, political and economic barriers (e.g. political power of homeowners, impacts on employment and the financial sector) cannot hide that more equitable use of housing is likely necessary to meet England's unmet housing need without transgressing national sustainability objectives. This study shows that in this case theoretical pathways to simultaneously achieving infrastructure, housing and ecological SDGs do exist, but they require a significant change from the business as usual strategy for satisfying society's housing needs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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